Principal Component Analysis of Physical, Color, and Sensory Characteristics of Chicken Breasts Deboned at Two, Four, Six, and Twenty-Four Hours Postmortem[1]

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ABSTRACT The effects of various postchill deboning times on functional, color, yield, and sensory attributes of broiler breast meat were determined. Broiler breast muscles were deboned at 2, 4, 6, and 24 h postmortem, and pH, color change, cooking yield, shear force values, and sensory traits of the breast meat were recorded. Data were examined by multivariate data analysis, namely principal component analysis (PCA). Averages of 13 variables (pH, Δa^*, shear force, and sensory attributes of cardboardy, wet feathers, springiness, cohesiveness, hardness, moisture release, particle size, bolus size, chewiness, and metallic aftertaste-afterfeel) decreased gradually as deboning time increased from 2 to 24 h, especially for shear values after 4 h of postmortem aging. Univariate correlation coefficients among 24 variables indicated several significant correlations. Warner-Bratzler shear force had high positive correlations with 5 sensory texture attributes (cohesiveness, hardness, particle size, bolus size, and chewiness). The parameters of pH, ΔL^*, Δa^*, Δb^*, and cooking yield were not obviously correlated with shear force values or any of the 18 sensory characteristics. PCA score plot showed no clear separation of the breast muscles deboned at different postmortem times, but it was still possible to differentiate them. The loading biplot suggested that 18 variables were effective in sample differentiation, including ΔL^*, shear force, cooking yield, 6 sensory flavor attributes (brothy, cardboardy, wet feathers, blood / serumy, salty, and sour), all sensory texture attributes except springiness, and all afterfeel-aftertaste properties.

(*Key words*: broiler breast, deboning time, principal component analysis, sensory property, tenderness)

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INTRODUCTION

Acceptably tender broiler breast meat (pectoralis major) requires postmortem aging time of 4 to 6 h before deboning (Klose et al., 1971; Lyon et al., 1985; Dawson et al., 1987). Postmortem aging of the entire carcass or fronthalf is time consuming and costly due to storage space and labor required (Hirschler and Sams, 1998). Various techniques, including electrical stimulation (Sams et al., 1989; Dickens and Lyon, 1995; Dickens et al., 2002), and postchill flattening or extended holding of deboned breasts (Lyon et al., 1992 a,b), have been evaluated to reduce the need for postmortem aging time while optimizing textural characteristics of ready-to-eat products.

To provide poultry processors with accurate, reliable, and rapid information on the evaluation of meat quality attributes and, further, to facilitate the efficiency of new processing techniques, researchers at the USDA Agricultural Research Service have been focusing on the relationships between sensory attributes and changes in the production process (Lyon and Lyon, 1990a,b, 1991, 1996, 1997; Lyon et al., 1994). In these studies, trained sensory panels and instrumental measurements were used together to draw conclusions and make decisions about meat quality. Instrumental methods, such as the Warner-Bratzler (WB) shear force (Bratzler, 1949), can measure characteristics that are directly related to the physical components of meat products and can provide reliable information about meat quality. However, human subjects go beyond the physical components to describe a wide range of factors involved in mastication and afterfeel / aftertaste sensations, such as appearance, flavor, and texture. Sensory panels provide complementary information to instrumental method, and neither can be

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Abbreviation Key: PC = principal component; PCA = principal component analysis; WB = Warner-Bratzler.

replaced. For example, instruments do not account for the juiciness and other moisture-related characteristics that panelists may perceive while chewing, and panels may identify and quantify more specific texture attributes that are not measured instrumentally. Meanwhile, relationships might exist between instrumental measurements and sensory panel evaluations. Previous studies have established a range of instrumental shear force values corresponding to different portions of the consumer texture scale, which enables commercial processors to relate the meaning of instrumental shear values to terms of relative toughness/tenderness of broiler breast meat (Lyon and Lyon, 1990b, 1991).

In order to completely describe the characteristics of meats, a variety of chemical, physical, color, and sensory analyses are necessary. Each type of analysis contributes specific and important information on overall meat quality. In other words, a meat sample might be characterized with different techniques, resulting in many diverse parameters (variables). Generally, it is difficult to obtain a comprehensive overview of many meat samples with a number of variables. Therefore, it might be useful to reduce the number of variables to describe the meats.

The main objective of this study was to use a multivariate statistical method, namely principal component analysis (PCA) (Massart et al., 1988; Naes et al., 1996), to analyze the variations of physical, color, and sensory properties of broiler breast meat deboned at different times after chilling. PCA operation makes it possible to distinguish meat samples and also to identify the most important variables in a multivariate data matrix.

MATERIALS AND METHODS

Broiler Samples

A total of 144 commercially grown, mixed-sex broilers were used in the study. Broiler carcasses (900 to 1,375 g dressed weight) were obtained from a local processing plant immediately after the flow-through, paddle-type chiller. Prechill and chill time averaged 60 to 65 min. The carcasses were placed in coolers and transported to the Russell Research Center laboratory (15 min).

Postmortem Deboning Times

In each of 4 replications, 36 carcasses were randomly subdivided into 4 groups of 9 carcasses according to the time that the breast muscles (pectoralis major) were to be removed. Four groups were designated for the postmortem deboning times of 2, 4, 6, and 24 h. Breast muscles for the 2 h group were removed from carcasses within 15 to 25 min of arrival at the laboratory. Carcasses aged at 4, 6, or 24 h prior to muscle removal were kept on ice in containers placed in a 2°C cold room until the appropriate deboning time. Muscles were removed from the left and right sides of each carcass using the technique of Hamm (1981). Right breasts were individually placed in labeled polyethylene heat and seal bags, sealed, and placed in a –30°C freezer prior to subsequent cooking for shear force, cooking loss, and sensory evaluation. Meanwhile, raw left breasts were evaluated for pH, visible near-infrared spectral and instrumental color measurement and again after cooking. The entire study was replicated 4 times and completed in 2 wk.

Color Measurement

Instrumental color measurements of both raw and cooked left breasts were performed using a colorimeter[3] (Minolta CR-210), calibrated throughout the study using a standard white ceramic reference (illuminant C). Random readings, each the average of 3 measurements, were taken at 3 different locations on the skinless topside of each sample. The 3 location readings were averaged, and color for each sample was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*). The data were presented for each of the muscles by the cooking-induced changes in color (Δ) for lightness (ΔL*), redness (Δa*), and yellowness (Δb*). Visible near-infrared spectral measurements were made at the same time (data not presented here).

pH Measurement

Immediately following the color and spectral measurements, 2 g of raw left muscles were put into a 50-mL plastic test tube containing 25 mL of 5 m**M** iodoacetic acid (sodium salt)[4] and 150 m*M* KCl[4], and homogenized using a PT 10/35 polytron mixer.[5] Before recording the pH values of the solutions on a Sentron model 2001 pH meter,[6] the electrode was rinsed with distilled water and dried with soft tissue paper.

Cooking of Breast Muscles

For each replication (n = 4), individual frozen and bagged samples were cooked by immersing the individual bags in 85°C water for 25 min to achieve a maximum internal temperature of 80°C. After cooking, the bags were tempered at room temperature before opening to drain the liquid. Cooking yield was calculated by dividing cooked weight by the prefreezing weight and multiplying by 100.

Cooked breasts were sectioned for sensory and instrumental evaluations, after a similar sampling scheme as outlined by Lyon and Lyon (1996). Anterior and posterior ends of the muscles were discarded. Two 1.9 cm wide strips were removed from the breast by cutting around a template aligned parallel to the muscle fibers and adjacent to the anterior end. One strip was used for instrumental evaluation. The second strip was cut into 2 subsections (1.9 cm high × 1.9 cm wide) and used for the sensory evaluation. Each panelist received 2 subsections from a single breast piece.

[3]Minolta Corp., Ramsey, NJ.
[4]Sigma Chemical Co., St. Louis, MO.
[5]Brinkmann Instruments, Westbury, NY.
[6]Sentron, Gig Harbor, WA.

Warner-Bratzler Shear Force Measurement

Intact strips for instrumental evaluations were covered with a plastic wrap and then sheared within 3 h of cooking. At room temperature, the samples were sheared perpendicular to the longitudinal orientation of the muscle fibers using a Warner-Bratzler (WB) shear blade (1 mm thick) attached to a Texture Analyzer TA-XT2,[7] equipped with a 25-kg load cell (50-kg capacity). Test speed was 4.2 mm / s; travel distance was 55 mm, and calibration distance was 1 mm. Maximum force measured to cut the strips was expressed as kilograms. For each cooked breast, the strip was sheared in 2 locations, and the average of the maximum forces was used for data analysis.

Sensory Evaluation

Sensory profiles were determined by a 9-member trained descriptive panel. In 2-h panel sessions (8 h total), each panelist evaluated 2 cubed samples from a single breast sample per treatment (9 panelists × 9 breast samples (1 fillet / panelist) = 9 samples for each treatment for 4 replications). The numerical intensity scale for each attribute ranged from 0 = none to 15 = extreme. The definition of 18 sensory attributes and the procedure and equipment for sensory evaluation have been described in detail in earlier reports (Lyon and Lyon, 1990a,b, 1996, 1997; Lyon et al., 1994).

Chemometric Model

The matrix consisted of 144 objects (36 breast samples from each deboning time at 2, 4, 6, and 24 h) and 24 variables (pH, ΔL*, Δa*, and Δb*, cook yield, WB shear force, and 18 sensory attributes). The data matrix was submitted into the Unscrambler software (Version 7.6)[8] to perform principal component analysis (PCA) with the weighting of standardization. Full cross-validation was used as the validation method. PCA is a useful statistical method for visualizing and interpreting large datasets by forming fewer composite variables (called principal components or PCs).

RESULTS AND DISCUSSION

Variations of pH, Color Change, Cooking Yield, Shear Value, and Sensory Attributes

Table 1 summarizes the means and standard deviations of variations in pH, color change (ΔL*, Δa*, and Δb*), cook yield, WB shear force, and 18 sensory attributes of breast muscles removed from the carcasses at 2, 4, 6, and 24 h postmortem, respectively. In general, averages of 13 variables (pH, Δa*, shear force, cardboardy, wet feathers, springiness, cohesiveness, hardness, moisture release, particle size, bolus size, chewiness, and metallic aftertaste-afterfeel) decreased steadily with increase in deboning time.

The pH value decreased gradually from 2 to 6 h and remained constant from 6 to 24 h postmortem, with an average of 6.01 over this period. The decline in pH suggested complex biochemical reactions during postmortem aging, although it was not statistically significant, and the ultimate pH values were higher (5.98) than others noted in the literature (Schreuers, 2000).

Compared with little change in ΔL*, relatively large fluctuations in Δa* and Δb* suggested that the muscles generally lost redness (lower Δa*) and gained yellowness (higher Δb*) more easily as the deboning time increased. Also, the increment in cooking yield was observed along with deboning time, but it was not statistically significant.

The WB shear force values decreased, as expected, with deboning time. The muscles deboned at the earlier postmortem time required significantly more force to shear (less tender) than did the muscles left on the skeletal frame longer. This observation was consistent with previous reports (Klose et al., 1971; Lyon et al., 1985; Dawson et al., 1987) and emphasized the importance of an aging period prior to breast muscle removal from the carcass. Under traditional processing schemes, a minimum of 4 h aging appears to be necessary for stable and acceptable tenderness in cooked broiler breast meat.

The sensory data also indicated differences due to the deboning times. There was a significant reduction in the values of 2 sensory flavor attributes (cardboardy and wet feathers), 7 sensory texture attributes (springiness, cohesiveness, hardness, moisture release, particle size, bolus size, and chewiness), and one afterfeel-aftertaste attribute (metallic) for muscles deboned from 2 to 24 h postmortem. Other sensory properties changed very little during the period.

The significant differences in 13 variables (Δa*, Δb*, WB shear force, cardboardy, wet feathers, springiness, cohesiveness, moisture release, hardness, particle size, bolus size, chewiness, and metallic attributes) might indicate that the chemical, physical, and structural changes in the muscles due to the deboning times were detected in the cooked meats. The changes in magnitude were not linear over the time frame. Apparently, the muscles deboned at longer postmortem times became more tender and had lower cardboardy, wet feathers, springiness, cohesiveness, moisture release, hardness, particle size, bolus size, chewiness, and metallic property than any others with less aging times. Meanwhile, the muscles from the longer postmortem time appeared to be less red and more yellow during the cooking than those that had undergone less postmortem time.

There was much more variability (higher SD) in comparing muscles at the earlier deboning times. For example, there was a wider range of shear forces and sensory texture scores (such as cohesiveness and chewiness) for breast muscles deboned 2 h postmortem. In general, variability decreased with increased deboned time. This finding was probably due to the complete depletion of energy

[7]Texture Technologies Corp., Scarsdale, NY.
[8]CAMO ASA, Oslo, Norway.

TABLE 1. Means and standard deviations for pH, CIELAB color change, cooking yield, Warner-Bratzler shear force, and sensory traits of chicken breast muscles removed from the carcasses at various times after chilling

Breast characteristic	Deboning time (h)				
	2[1]	4[1]	6[1]	24[1]	All
pH	6.06 ± 0.20	6.02 ± 0.18	5.98 ± 0.18	5.98 ± 0.16	6.01 ± 0.18
ΔL^*[2] (%)	70.56 ± 7.59	69.68 ± 7.52	70.71 ± 9.29	72.03 ± 10.14	70.74 ± 8.66
Δa^*[2] (%)	–24.30 ± 16.98	–25.16 ± 15.98	–29.07 ± 15.28	–34.87 ± 14.39	–28.35 ± 16.08
Δb^*[2] (%)	257.53 ± 126.45	267.18 ± 148.95	404.57 ± 372.85	345.38 ± 503.33	318.66 ± 330.18
Cooking yield[3] (%)	73.79 ± 3.00	74.68 ± 2.69	75.14 ± 3.21	75.33 ± 3.03	74.74 ± 3.01
Shear force (kg)	9.40 ± 3.26	7.08 ± 2.83	5.79 ± 1.74	3.90 ± 1.01	6.54 ± 3.10
Sensory flavor[4]					
Brothy	3.58 ± 0.92	3.77 ± 0.67	3.99 ± 0.74	3.73 ± 0.69	3.77 ± 0.77
Chickeny-meaty	4.17 ± 0.56	4.22 ± 0.58	4.26 ± 0.48	4.12 ± 0.45	4.19 ± 0.52
Cardboardy	2.87 ± 1.06	2.71 ± 0.95	2.63 ± 0.86	2.39 ± 0.97	2.65 ± 0.97
Wet feathers	2.88 ± 0.97	2.83 ± 0.86	2.77 ± 0.95	2.53 ± 0.88	2.75 ± 0.92
Bloody-serumy	3.30 ± 1.24	3.48 ± 1.17	3.48 ± 1.36	3.12 ± 1.14	3.34 ± 1.23
Sweet	2.21 ± 0.80	2.11 ± 0.94	2.22 ± 0.89	2.40 ± 0.66	2.24 ± 0.79
Salty	2.05 ± 0.74	1.91 ± 0.85	2.02 ± 0.87	2.19 ± 0.73	2.04 ± 0.80
Sour	2.89 ± 0.95	2.71 ± 0.78	2.85 ± 0.85	2.95 ± 0.77	2.85 ± 0.84
Sensory texture[4]					
Springiness	3.81 ± 1.10	3.87 ± 1.25	3.81 ± 1.24	3.42 ± 1.30	3.73 ± 1.23
Cohesiveness	5.95 ± 1.70	5.63 ± 1.66	5.08 ± 1.51	4.61 ± 1.38	5.32 ± 1.63
Hardness	5.60 ± 1.02	5.45 ± 1.27	5.01 ± 1.11	4.34 ± 1.18	5.10 ± 1.24
Moisture release	3.82 ± 0.82	3.68 ± 0.86	3.69 ± 0.68	3.57 ± 0.87	3.69 ± 0.81
Particle size	3.74 ± 0.76	3.71 ± 1.05	3.36 ± 0.95	3.01 ± 0.93	3.46 ± 0.97
Bolus size	4.16 ± 0.76	3.95 ± 0.99	3.57 ± 0.98	3.32 ± 0.98	3.75 ± 0.98
Chewiness	5.63 ± 1.15	5.18 ± 1.35	4.66 ± 1.28	4.27 ± 0.97	4.96 ± 1.28
Toothpack	3.66 ± 1.00	3.83 ± 1.06	3.68 ± 0.96	3.57 ± 0.94	3.68 ± 0.99
Afterfeel-aftertaste[4]					
Metallic	3.31 ± 1.17	3.31 ± 1.13	3.06 ± 1.26	3.09 ± 1.28	3.19 ± 1.20
Oily-greasy	1.28 ± 0.92	1.18 ± 0.96	1.28 ± 1.00	1.27 ± 0.90	1.26 ± 0.94

[1]Average of 36 measurements for each of 4 deboning times postmortem.

[2]Calculation of ΔL^*, Δa^*, and Δb^* with the formula $\Delta y^* = [(y_{cooked} - y_{raw}) / y_{raw}] \times 100\%$, where y = L*, a*, or b*.

[3]Calculation of cooking yield with the formula $w^* = (w_{cooked} / w_{raw}) \times 100\%$.

[4]0 = none, 15 = extreme.

in individual muscles from individual birds as they went through the biochemical process (Schreuers, 2000). By 6 h or more postmortem, most breast muscles of them have gone through the biochemical stages, and so these samples varied less (lower SD).

The univariate correlation coefficients between 2 of 24 variables are shown in Table 2. The effect of deboning time was not considered, and all available samples were used. There existed several significant correlations among pH, color change, cook yield, WB shear force, and the sensory attributes. Besides the positive and strong correlation with ΔL^*, pH correlated with Δa^* positively and moderately and also with 2 sensory flavor notes (blood-serumy and sour) negatively and moderately. None of the color attributes, ΔL^*, Δa^*, and Δb^*, was correlated significantly with WB shear force or any of the 18 sensory characteristics. Color of meat is probably not related directly to actual texture and flavor but plays an important part in visual appraisal of meat prior to ingestion.

As expected, WB shear force had strong and positive correlations with 4 sensory texture attributes (hardness, particle size, bolus size, and chewiness). There was a moderate correlation with cohesiveness, as well as a moderate and negative correlation with cook yield. WB shear force had insignificant correlations with sensory flavors and afterfeel-aftertaste properties.

Five sensory flavors, including cardboardy, wet feathers, blood-serumy, sweet, and sour, had positive correlations with each other and with several sensory texture attributes. They showed low correlations with the remaining sensory flavors.

Positive and strong correlations were observed among most of the sensory texture attributes (i.e., springiness, cohesiveness, hardness, particle size, bolus size, and chewiness). These attributes also showed moderate and positive correlations with 2 other textures (moisture release and toothpack). Afterfeel-aftertaste properties significantly correlated with several sensory flavor and texture attributes but were not correlated with pH, color change, cook yield, or WB shear force.

PCA of pH, Color Change, Cook Yield, Shear Force, and Sensory Characteristics

The data matrix (144 objects × 24 variables) was used to perform PCA with the weighting method of standardization. Seven principal components (PC) were extracted that accounted for 69.2% of the total variation. The first 4 of these PC accounted for 52.5% of the variance in the 24 variables (PC1 = 23.2%, PC2 = 13.6%, PC3 = 8.8%, PC4 = 6.9%).

TABLE 2. Univariate correlation coefficients for 24 variables[1,2,3]

Breast characteristic	pH	ΔL*	Δa*	Δb*	Yield	WBSF	BRO	CHI	CBD	WFE	BLO	SWT	SALT	Sour	SPR	COH	HARD	MR	PS	BS	CHEW	TP	MET
ΔL*	0.41																						
Δa*	0.29	–0.15																					
Δb*	0.07	0.08	–0.08																				
Cooking yield	0.19	0.47	0.04	–0.04																			
Shear force	0.19	0.23	0.21	–0.14	–0.32																		
Sensory flavor																							
Brothy	–0.06	–0.07	0.08	0.08	0.11	–0.06																	
Chicken-meaty	–0.11	–0.09	0.04	–0.01	0.02	–0.01	0.23																
Cardboardy	–0.17	–0.19	–0.05	–0.13	–0.21	0.25	–0.15	0.19															
Wet feathers	–0.14	–0.13	–0.07	–0.13	0.07	0.00	0.19	0.20	0.57														
Blood-serumy	–0.22	–0.18	0.02	–0.17	–0.13	0.09	0.21	0.30	0.43	0.68													
Sweet	–0.05	–0.10	0.06	–0.06	0.00	–0.06	0.17	0.21	–0.07	–0.10	0.08												
Salty	–0.06	–0.15	0.04	–0.08	0.00	0.04	–0.04	0.17	0.22	0.04	0.09	0.53											
Sour	–0.24	–0.24	0.00	–0.23	–0.06	–0.03	0.16	0.18	0.37	0.52	0.64	0.26	0.26										
Sensory texture																							
Springiness	0.01	–0.05	0.05	0.14	0.03	0.11	0.17	–0.02	0.01	–0.03	–0.04	–0.28	–0.06	0.01									
Cohesiveness	0.04	0.01	0.02	–0.02	–0.08	0.30	0.12	0.07	–0.07	0.14	0.27	–0.30	–0.32	0.12	0.45								
Hardness	0.03	–0.08	0.11	–0.04	–0.12	0.41	0.24	0.11	0.09	0.22	0.30	–0.27	–0.26	0.19	0.48	0.75							
Moisture release	0.07	0.03	0.07	–0.01	0.17	0.00	0.23	0.09	–0.08	0.15	0.09	–0.17	–0.35	0.19	0.30	0.27	0.34						
Particle size	0.00	–0.14	0.05	–0.14	–0.10	0.40	0.08	0.10	0.35	0.23	0.20	–0.25	0.10	0.19	0.32	0.48	0.60	0.21					
Bolus size	0.02	–0.03	–0.03	–0.20	–0.04	0.39	–0.11	0.08	0.41	0.24	0.21	–0.30	–0.13	0.19	0.27	0.44	0.55	0.27	0.82				
Chewiness	0.12	–0.06	0.04	–0.10	–0.13	0.51	0.14	0.08	0.03	0.17	0.32	–0.13	–0.21	0.17	0.21	0.66	0.65	0.24	0.57	0.60			
Toothpack	–0.09	0.01	–0.02	–0.17	–0.02	0.00	0.17	0.09	0.24	0.38	0.49	0.01	–0.09	0.33	0.11	0.27	0.21	0.35	0.20	0.22	0.38		
Afterfeel-aftertaste																							
Metallic	–0.11	–0.14	0.02	–0.13	–0.21	0.13	0.34	0.18	0.16	0.53	0.76	0.17	0.08	0.51	–0.12	0.32	0.29	–0.08	0.11	0.02	0.39	0.40	
Oily-greasy	0.16	0.04	0.12	0.03	0.10	0.03	–0.26	0.04	–0.06	–0.40	–0.41	0.15	0.35	0.00	–0.09	–0.45	–0.39	–0.27	–0.37	–0.30	–0.40	–0.30	–0.42

[1]Cooking yield (Yield), Warner-Bratzler shear force (WBSF), brothy (BRO), chickeny-meaty (CHI), cardboardy (CBD), wet feathers (WFE), bloody-serumy (BLO), sweet (SWT), salty (SALT), springiness (SPR), cohesiveness (COH), hardness (HARD), moisture release (MR), particle size (PS), bolus size (BS), chewiness (CHEW), toothpack (TP), and metallic (MET).

[2]All 144 samples were used to determine the correlation coefficients for any 2 of 24 variables with the exception of cooking yield for which 142 samples were used.

[3]Absolute value greater than 0.35 was objectively considered to have significant correlation, and a value between 0.20 and 0.35 had moderate correlation.

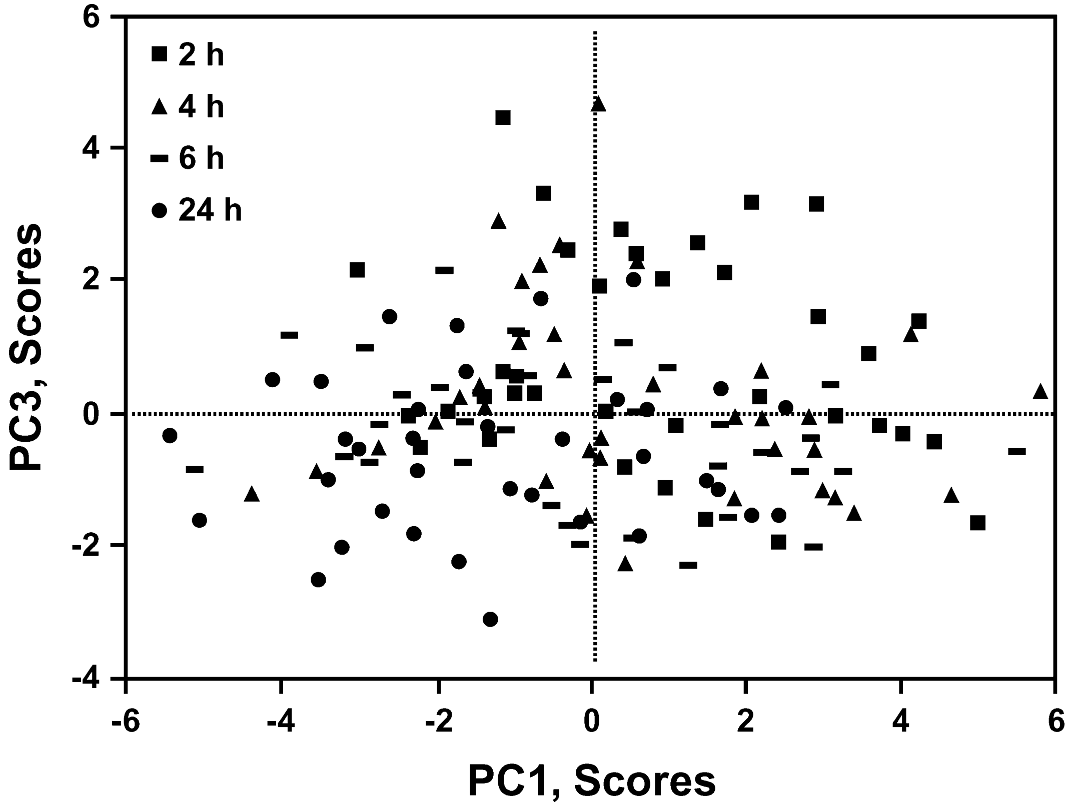

FIGURE 1. Principal component (PC)1 versus PC3 scores-scores plot of 144 cooked muscles deboned at 2 h (■), 4 h (◆), 6 h (—), and 24 h (●) postmortem and after the chiller.

The plot of PC1 vs PC3 scores provided the better visualization of the samples and is shown in Figure 1. The plot of these data suggested that the cooked muscles could not be separated clearly by different deboning times. However, careful analysis indicated that some portion of the meat samples did vary by deboning time. For example, for muscles deboned at 2, 4, 6, and 24 h postmortem there were 23, 19, 16, and 11 samples, respectively, that had positive PC1 values (PC1 > 0), and 23, 16, 14, and 12 samples, respectively, that had positive PC3 scores (Table 3). Meanwhile, the number of muscles with positive PC1 and PC3 scores decreased, and the number of muscles with negative values on PC1 and PC3 increased as debone time increased from 2 to 24 h postmortem. The observation suggests that generally, with increased debone time, the cooked muscles had a tendency to be negative on both PC1 and PC3. Hence, it could be possible to discriminate the groups of muscles deboned at different times, indicating the differences in characteristics of meats during the postmortem interval.

TABLE 3. Relationship between principal component (PC) scores and deboning times[1]

	Deboning time (h)			
PC Score	2	4	6	24
PC1 > 0	23	19	16	11
PC1 < 0	13	17	20	25
PC3 > 0	23	16	14	12
PC3 < 0	13	20	22	24
PC1 > 0 and PC3 > 0	13	6	5	5
PC1 < 0 and PC3 < 0	3	7	11	18

[1]Thirty-size samples for each of 4 deboning times.

Table 4 summarizes the loadings of PC1 through PC4 for 24 variables. Loadings are the correlations between an individual variable and the new variable, i.e., PC. It showed that the most important variables for PC1 were WB shear force, 4 sensory flavor notes (cardboardy, wet feathers, blood-serumy, and sour), all the sensory texture attributes except springiness, and all afterfeel-aftertaste parameters. All but one of these variables had positive loadings. PH, ΔL^*, Δa^*, Δb^*, cook yield, 4 sensory flavor attributes (brothy, chickeny-meaty, sweet, and salty) and 1 sensory texture attribute (springiness) had less significant effects on PC1. Hence, PC1 was defined by WB shear force and most sensory attributes of cooked meat. In fact, in the loading biplot (Figure 2), WB shear force and most sensory variables were located farther from the origin of PC1 than pH, ΔL^*, Δa^*, Δb^*, cook yield, brothy, chickeny-meaty, sweet, salty, and springiness and were placed to the right or left in the graph. Similarly, ΔL^*, all sensory flavor attributes except brothy, all sensory texture attributes except toothpack, and 1 afterfeel-aftertaste (metallic) were important for PC2.

The PC3 was mostly dominated by ΔL^*, WB shear force, cook yield, brothy, cardboardy, salty, moisture release, particle size, bolus size, toothpack, and all afterfeel-aftertaste properties. PC4 was mostly dominated by pH,

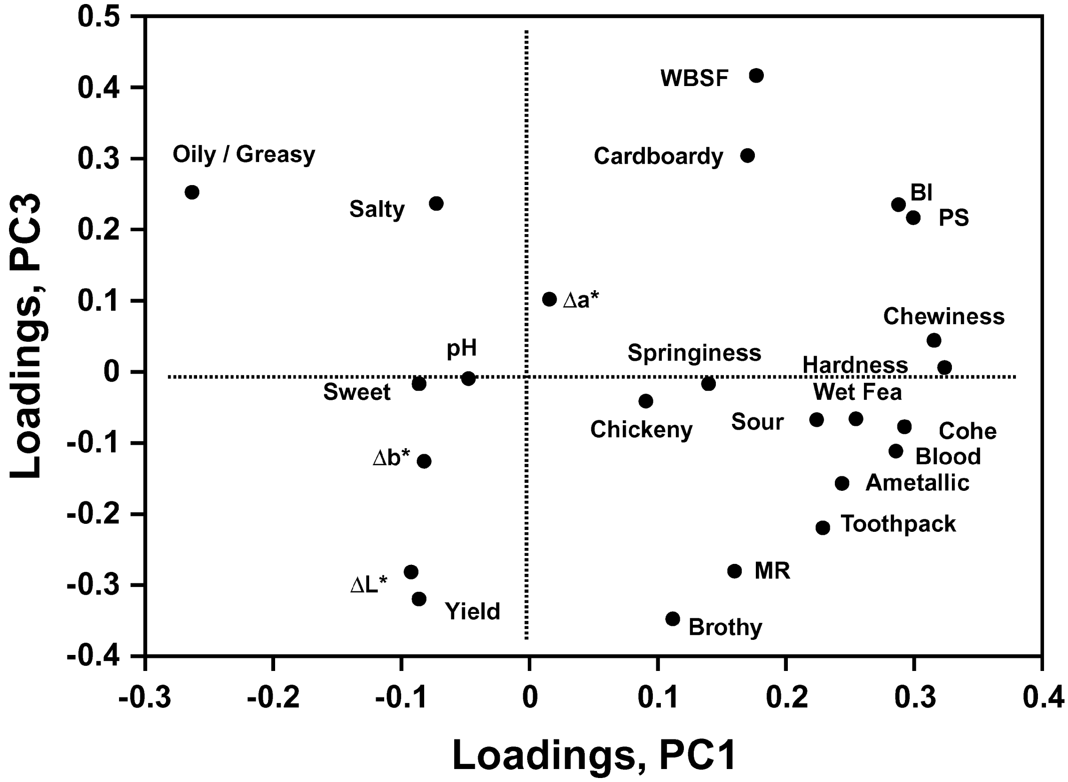

FIGURE 2. Biplot of principal component (PC)1 versus PC3 loadings for 24 variables. Warner-Bratzler shear force (WBSF), bolus size (BI), particle size (PS), wet feathers (Wet Fea), cohesiveness (Cohe), bloody-serumy (Blood), metallic (Ametalic), and moisture release (MR).

Δa*, WB shear force, brothy, chickeny-meaty, cardboardy, wet feathers, sweet, salty, chewiness, and oily-greasy.

Large positive loadings (Table 4) or variables plotted in the right, top quadrant of the biplot (Figure 2) contributed largely to the sample scores in the right quadrant in the scores plot (Figure 1). The same was true for negative loadings (variables to the left or the bottom) and variables at the top of the biplot. Variables clustered together had similar effects on the scores and were positively correlated. Variables plotted close to the axes had lower contributions to the position of cooked meat than those further away from the axes. Variables located opposite to each other tended to have a negative effect on the meat position and also tended to have negative correlations.

Scores presented in Figure 1 and Table 3 indicated that, for muscles left on the skeletal frame longer, WB shear force and 5 sensory texture attributes (hardness, chewiness, cardboardy, bolus size, and particle size) decreased greatly, whereas ΔL*and cook yield increased. In other words, early deboned muscles showed stronger hardness, chewiness, cardboardy, bolus size, particle size, and WB shear force than those deboned after longer postmortem time. Early deboned muscles also had the lowest cook yield and least change in ΔL*.

Because WB shear force, cardboardy, wet feathers, bloody-serumy, sour, springiness, and all afterfeel-aftertaste parameters were significantly associated with the

TABLE 4. Loadings of PC1,[1] PC2, PC3, and PC4 for 24 variables

Variable	PC1	PC2	PC3	PC4
pH	–0.048	0.022	–0.004	0.356
ΔL*	–0.092	0.176	–0.281	–0.004
Δa*	0.016	0.039	0.105	0.467
Δb*	–0.082	0.105	–0.122	–0.023
Cooking yield	–0.085	0.093	–0.317	0.106
Shear force	0.177	0.095	0.419	0.240
Sensory flavor				
Brothy	0.112	–0.071	–0.345	0.300
Chickeny-meaty	0.091	–0.169	–0.041	0.208
Cardboardy	0.170	–0.217	0.307	–0.253
Wet feathers	0.253	–0.251	–0.063	–0.183
Bloody-serumy	0.286	–0.308	–0.111	–0.015
Sweet	–0.086	–0.314	–0.016	0.391
Salty	–0.074	–0.310	0.241	0.262
Sour	0.224	–0.315	–0.063	0.016
Sensory texture				
Springiness	0.139	0.243	–0.015	0.058
Cohesiveness	0.293	0.235	–0.075	0.085
Hardness	0.323	0.212	0.011	0.133
Moisture release	0.160	0.167	–0.277	0.021
Particle size	0.298	0.163	0.221	–0.025
Bolus size	0.287	0.177	0.237	–0.119
Chewiness	0.314	0.160	0.046	0.176
Toothpack	0.228	–0.100	–0.215	–0.041
Afterfeel-aftertate				
Metallic	0.244	–0.279	–0.156	0.132
Oily-greasy	–0.262	–0.006	0.256	0.198
Variation accounted for (%)	23.2	13.6	8.8	6.9
Cumulative	23.2	36.8	45.6	52.5

[1]PC = principal component.

PC1, and ΔL^*, WB shear force, cook yield, brothy, cardboardy, salty, moisture release, particle size, bolus size, toothpack and all afterfeel-aftertaste attributes were with PC3, the variations in these 18 attributes were clearly more important than other characteristics such as pH, Δa^*, Δb^*, chickeny-meaty, sweet, and springiness, which, however, might become significant on other PC. The PCA results provided useful information about the similarities and differences for the cooked muscles with various deboning times, as well as the significance of 18 variables and the relationship among variables themselves.

In summary, the objective (pH, color change, cooking yield, and WB shear force) and the sensory attributes showed the effect of postmortem deboning times on the sensory flavor and texture as well as afterfeel-aftertaste attributes. Univariate correlation coefficients among variables indicated several significant correlations. For example, WB shear force had strong and positive correlations with five sensory texture attributes (cohesiveness, hardness, particle size, bolus size, and chewiness) and had insignificant correlations with sensory flavor and afterfeel-aftertaste attributes. None of the variables of pH, ΔL^*, Δa^*, Δb^*, and cook yield variables were correlated significantly with WB shear force or any of the 18 sensory characteristics. Although PCA results showed no clear separation of all the same muscles deboned at different postmortem periods, it could be still possible to differentiate them. However, the techniques to obtain either objective or sensory properties are destructive, time-consuming, and unsuitable for online implementations. Hence, it is desirable to develop a fast, nondestructive, and online/at-line near-infrared spectroscopy technique for qualitative and quantitative determination of poultry meat eating qualities.

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